Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 4 (2011) 688–692

Energy Procedia

www.elsevier.com/locate/procedia

Membrane Contacting Process for CO_2 Desorption

Sakarin Khaisri[a], David deMontigny[b*], Paitoon Tontiwachwuthikul[b], Ratana Jiraratananon[a]

[a] Department of Chemical Engineering, King Mongkut's University of Technology Thonburi, Bangkok 10140, Thailand

[b] International Test Centre for CO_2 Capture, University of Regina, Regina, SK, Canada S4S 0A2

* Corresponding author: Telephone: +1 (306) 337-2277 Fax number: +1 (306) 585-4855

E-mail address: david.demontigny@uregina.ca

Abstract

A membrane contactor based desorption process was developed to strip carbon dioxide (CO_2) from loaded monoethalamine (MEA) solution. Nitrogen (N_2) gas was used as a stripping gas instead of steam in a conventional column. Polytetrafluoroethylene (PTFE) hollow fiber membranes were used to test the desorption performance. The liquid solution was fed in the lumen while the stripping gas was fed through the shell side. The stripping gas, liquid velocities, operating temperature, and MEA concentration were all investigated for their effect on CO_2 desorption flux. It was found that the CO_2 desorption flux was relatively constant with an increase stripping gas velocity while the liquid velocity, operating temperature, and solution concentration could enhance CO_2 desorption flux in the membrane contactor based desorption process. However, an increase the solution concentration to 5 kmol m^{-3} resulted in a decrease in the CO_2 desorption flux due to the effect of viscosity.

Keywords: carbon dioxide, desorption, membrane contactor, monoethanolamine, polytetrafluoroethylene

1. Introduction

Since the beginning of the industrial revolution, the energy demand has increased dramatically, resulting in the burning of fossil fuels. The combustion of fossil fuels produces carbon dioxide gas, which should be removed from industrial flue gas streams. CO_2 has been the main contributor to global climate change, which has a huge impact on the environmental. The absorption of CO_2 into aqueous alkanolamines has been studied using conventional equipment such as packed columns, bubble columns, and spray columns. The typical process for CO_2 capture consists of two major units, absorption and desorption. Desorption is commonly done in conventional columns that have operational problems such as flooding, channeling, and entrainment. A few studies have reported on CO_2 desorption using conventional columns [1, 2]. Hollow fiber membrane contactors have been studied over the past few decades for CO_2 capture. The membrane contactors provide superior mass transfer performance when compared to conventional equipment. Due to the high interfacial area per volume, membrane contactors are a compact device. This leads to reduced capital cost and less energy consumption [3]. Results form the research have led to the development of membrane contactors for gas absorption. Most of the research has focused on absorption, but a few authors have developed regeneration units using membrane contactors. Koonaphapdeelert et al. [4] studied CO_2 desorption from MEA solutions in ceramic hollow fiber membrane contactors. They found that the height of the transfer unit (HTU) of the contactors was as low as 15 cm. The mass transfer resistance in the liquid phase was a dominant resistance in the process, which is the same behavior found in gas absorption membrane contactors. Ceramic membranes show high chemical and thermal stabilities, which are suitable to use at high temperature applications. However, ceramic membranes are extremely expensive because the fabrication method involves a high temperature sintering treatment.

The objective of this work was to develop a membrane contactor for CO_2 stripping from monoethanolamine solution. Polytetrafluoroethylene (PTFE) hollow fiber membranes were use in the experiments due to its high hydrophobicity, chemical resistance, and thermal stability. The effect of operating conditions, including gas and liquid velocities, solution temperature, and solution concentration, were investigated to study the desorption performance and mass transfer process in the membrane contactor based desorption process.

2. Materials and Methods

The membrane contactor developed for this work was used as a desorber. The membrane module was made from stainless steel to operate at a high operating temperature. A stainless steel module housed a removable membrane cartridge and was fitted with data sampling points to record the temperatures and CO_2 concentrations at the module inlet and outlet for both liquid and gas phases. The membrane module was insulated to prevent a heat loss and heat effects from the surrounding environment. PTFE membranes were potted with stainless steel discs. The PTFE membranes

doi:10.1016/j.egypro.2011.01.106

have and outer and inner diameter of 2.007 and 1.626 mm, respectively. The porosity and effective membrane length are 23% and 14 cm, respectively. The 50 PTFE hollow fibers were potted as a membrane cartridge.

Aqueous solutions of MEA were prepared to a desired concentration using de-ionized water. The MEA solutions were then loaded with CO_2 to a desired loading of 0.45 mol CO_2/mol MEA. Standard hydrochloric acid solution (1 N) was used as a titrant with methyl orange as an indicator. Nitrogen (N_2) gas was used as a stripping gas instead of steam, which is used in conventional stripping columns. Figure 1 shows the gas stripping membrane contactor used in this work and Figure 2 shows the experimental setup. The rich absorbent solution was fed into the lumen while the stripping gas stream was fed through the shell-side. The gas was introduced into the module before the liquid stream in order to prevent wetting problems. Each run was operated for at least 30 minutes before collecting any data to make sure that steady state conditions had been reached. At steady state conditions, the CO_2 outlet concentration in the gas stream was measured using the infrared analyzer (Nova Analytical Systems, model 302). A known volume of liquid was collected at steady state conditions for titration to determine the CO_2 loading in the MEA solution. CO_2 loading was determined to make sure that the mass balance error between the gas and liquid side was low, indicating the experiment was valid.

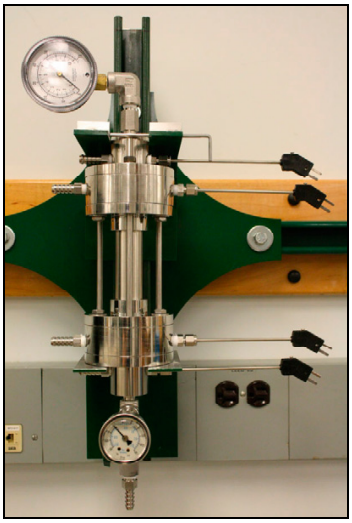

Figure 1: Stripping membrane module.

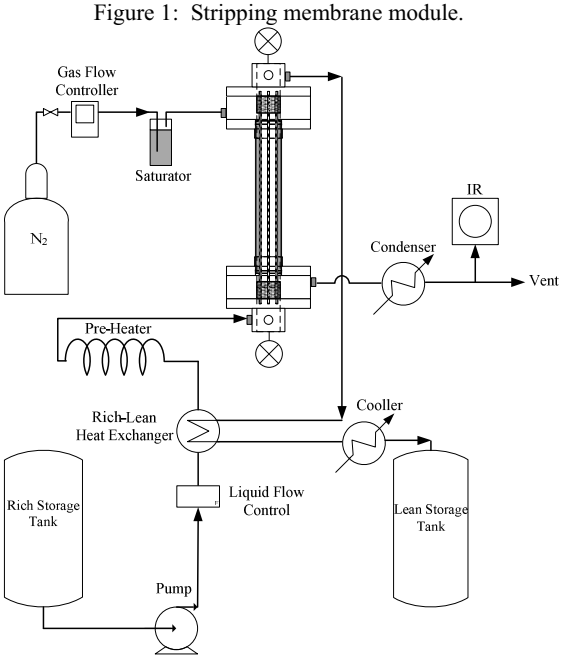

Figure 2: Experimental setup for the gas stripping membrane contactor.

3. Results and discussion

The effect of gas velocity was examined at 100 ºC rich solution temperature. Figure 3 shows the effect of stripping gas velocity on CO_2 desorption flux. It was found that that the change in CO_2 desorption flux with increasing gas velocity was negligible. This is because the main resistance to mass transfer is in the liquid film mass transfer coefficient. This is because the reaction between CO_2 and MEA is mainly in the liquid film. Khaisri et al. [5] calculated individual mass transfer coefficients in the membrane contacting process. They found that the gas phase mass transfer resistance had a contribution to the overall mass transfer resistance of roughly 5-10%. This was confirmed by Koonaphapdeelert [4] who found that the mass transfer in gas stripping membrane contactors was mainly controlled by the liquid film mass transfer coefficient.

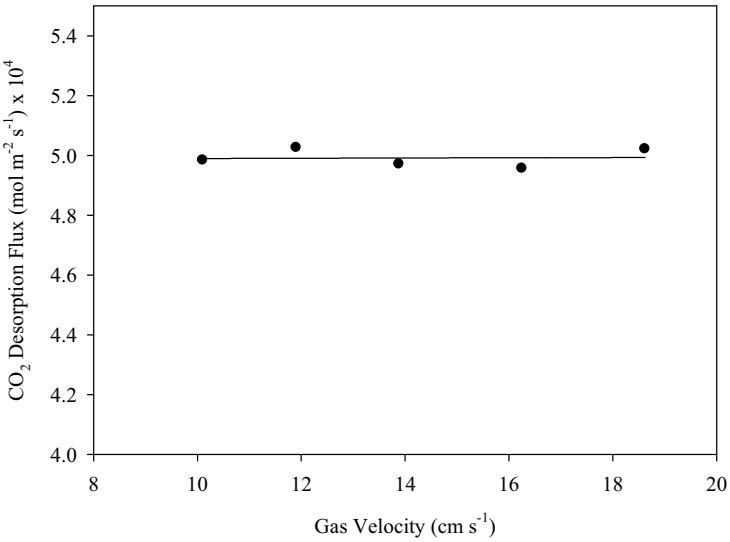

Figure 3: Effect of stripping gas velocity on CO_2 desorption flux.
(M_{MEA} = 3.0 kmol m^{-3}, v_L = 1.0 cm s^{-1}, T = 100 ºC)

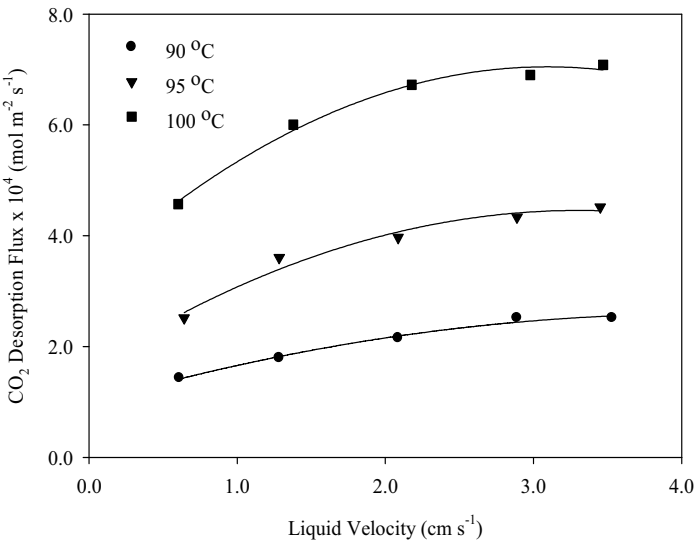

Figure 4: Effect of rich solution temperature on CO_2 desorption flux.
(M_{MEA} = 3.0 kmol m^{-3}, v_G = 10.0 cm s^{-1})

The effect of liquid velocities was shown in Figure 4. An increase in the liquid velocity resulted in an increase in the CO_2 desorption flux at any given operating temperature. The increase in the CO_2 desorption flux was attributed to an increased liquid phase mass transfer coefficient. The overall mass transfer coefficient could increase by increasing liquid or gas velocity. Additionally, the gas phase mass transfer resistance had a minor effect on the overall mass transfer coefficient. It can be concluded that the liquid phase mass transfer resistance is the main mass transfer resistance in the gas stripping membrane contactor. The results also confirmed previous experimental results. The effect of rich solution temperature was also shown in Figure 4. It is obvious that the CO_2 desorption flux increased with an increase in the solution temperature. The temperature directly affects the CO_2 equilibrium partial pressure, chemical reaction equilibrium constant, and diffusion coefficient. The equilibrium partial pressure of CO_2 increases exponentially with temperature by the factors of 5 to 8 with an increase in temperature of 10°C [6]. Therefore, the chemical reaction equilibrium constant decreases due to the effect of equilibrium partial pressure of CO_2. As a result, an increase in operating temperature leads to an increase in the driving force for the stripping of CO_2 from MEA solution.

Solution concentration showed a significant effect on the CO_2 desorption flux as seen in Figure 5. An increase MEA concentration from 3.0 to 5.0 kmol m^{-3} resulted an increase in CO_2 desorption flux. An increase in the MEA solution concentration leads to increase the amount of carbamate in the solution. The carbamate molecule can diffuse towards the gas-liquid interface so that CO_2 can be stripped off from the liquid solution. This leads to an increase in the driving force by increasing solution concentration. However, the CO_2 desorption flux started to decrease when the concentration increased from 5.0 to 7.0 kmol m^{-3} because of the effect of viscosity. The viscosity of MEA solution at 100 °C with a 0.45 CO_2 loading increases by roughly 65% and 200% when the solution concentration is increased from 3.0 to 5.0 and 7.0 kmol m^{-3}, respectively [7]. This behavior has also been seen in gas absorption membranes and packed columns [6, 8]**.** It is important to note that the corrosion rates in steel vessels and steel piping increase with an increase in solution concentration. This factor needs to be considered and minimized in terms of mass transfer rates.

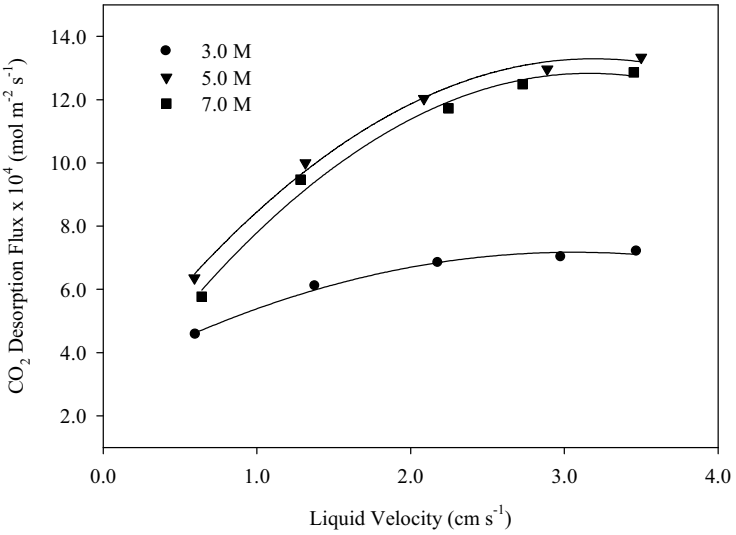

Figure 5: Effect of MEA concentration on CO_2 desorption flux.
(v_G = 10.0 cm s^{-1}, T = 100 °C)

4. Conclusion

A membrane contactor based desorption process was developed to strip CO_2 from MEA solution. PTFE hollow fiber membranes were used to test desorption performance. The effects of operating condition including gas and liquid velocities, solution temperature, and solution concentration were investigated. The experimental results showed that the stripping gas velocity had a minor effect on the CO_2 desorption flux while the liquid velocity and solution temperature had a significant effect on the CO_2 desorption flux. An increase in the liquid velocity and solution temperature resulted an increase in the mass transfer rate in the membrane contacting process. Solution concentration also affected the desorption performance as an increase in concentration from 3.0 to 5.0 kmol m^{-3} resulted in an increase in the CO_2 desorption flux. However, when the solution concentration increased to 7.0 kmol m^{-3} the desorption performance deteriorated because of the effect of viscosity. Overall, it can be concluded that membrane contactors can be used to strip CO_2 from rich amine solutions, and achieve a performance similarly to conventional desorber units.

Acknowledgements

The authors gratefully acknowledge the financial support from the Thailand Research Fund (TRF) through the Royal Golden Jubilee Ph.D. Program, the TRF Senior Research Scholar Grant, and from the International Test Centre for CO_2 Capture, University of Regina. We also would like to tank Markel Corporation for providing the PTFE membranes.

References

[1] F.A. Tobiesen and H.F. Svendsen. Study of a modified amine-based regeneration unit. Ind. Eng. Chem. Res. 2006; 45: 2489-2496.

[2] G.W. Xu, C.F. Zhang, S.J. Qin, and B.C. Zhu. Desorption of CO_2 from MDEA and activated MDEA solutions. Ind. Eng. Chem. Res. 1995; 34: 874-880.

[3] J.L. Li and B.H. Chen. Review of CO_2 absorption using chemical solvents in hollow fiber membrane contactors. Sep. Purif. Technol. 2005; 41: 109-122.

[4] S. Koonaphapdeelert, Z. Wu, and K. Li. Carbon dioxide stripping in ceramic hollow fibre membrane contactors. Chem. Eng. Sci. 2009; 63: 1-8.

[5] S. Khaisri, D. deMontigny, P. Tontiwachwuthikul, and R. Jiraratananon. A mathematical model for gas absorption membrane contactors that studies the effect of partially wetted membranes. J. Membr. Sci. 2010; 347: 228-239.

[6] R.H. Weiland, M. Rawal, and R.G. Rice. Stripping of carbon dioxide from monoethanolamine solutions in a packed column. AIChe J. 1982; 28: 963-973.

[7] R.H. Weiland, J.C. Dingman, D.B. Cronin, and G.J. Browning. Density and viscosity of some partially carbonated aqueous alkanolamine solutions and their blends. J. Chem. Eng. Data 1998; 43: 378-382.

[8] D. deMontigny, P. Tontiwachwuthikul, and A. Chakma. Comparing the absorption performance of packed columns and membrane contactors. Ind. Eng. Chem. Res. 2005; 44: 5726-5732.